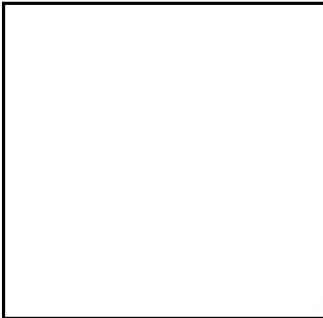


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VISUAL IMAGE INTEGRATION AS
A FUNCTION OF CONTRAST, PROJECTION RATE, AND
NUMBER OF INDEPENDENT PHOTOGRAPHS

Technical Report 760-1

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October 8, 1964

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SUMMARY

INTRODUCTION

That photographic signal-to-noise ratio can be improved through photographic superimposition has long been recognized. Practical photographic superimposition systems can be quite complex and expensive. Consequently, the question arises as to whether or not the recognizability of grain-limited photographic images can be improved by a rapid presentation of different photographs of the same image. The notion here is, with the aid of the visual system, that time may be sufficiently compressed to produce what might be called "perceptual" superimposition.

The purpose of this study was to explore various conditions under which image recognition might be enhanced by visual "superimposition" or "integration."

METHOD

The effects of three variables on the recognition of grain-limited images were studied: projection rate--2, 8, 16, and 24 frames per second; contrast--1.1:1, 1.71:1, and 3.83:1; number of independent photographs--2, 4, 8, and 16.

A total of 48 subjects participated in the main experiment. Twelve subjects served under each projection rate, therefore, each subject served under 12 experimental conditions (3 contrasts times 4 numbers of independent photographs). The subjects' task was to identify each of 20 black letters. The time taken to run each subject was 70 minutes. In addition, a control condition was run in which three subjects were required to identify the letters in each photograph under still projection conditions.

RESULTS

The results of the main experiment and of an additional experiment to evaluate learning effects indicated that considerable learning occurred during the course of the main experiment. Consequently, the joint effects of projection rate, contrast, and number of independent photographs could not be evaluated. But the separate effects of these three variables were evaluated.

The differences in projection rate had no effect on recognition accuracy.

The differences in contrast did produce reliable differences in recognition accuracy, but this result is not considered as evidence for "visual integration."

The differences in number of independent photographs also produced reliable differences in recognition accuracy. But this was not considered either as evidence for "visual integration" because the performances of the experimental (moving projection) and the control (still projection) groups did not differ.

There were large differences in performance among subjects. Under several conditions, the performance scores for a given projection rate ranged from 0% to 100%. The reliability of individual performances was very high. The average reliability for all experimental conditions was 0.94.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study did not provide evidence for "visual integration." This was probably because the projection rates used were too low. If there is a projection rate at which "visual integration" occurs, it can only be established empirically. It is suggested, therefore, that an informal investigation be conducted using higher projection rates and the photographs made for the present study. A full-scale study of the limits within which

"visual integration" works should be considered only if the results of the informal investigation indicate that it is worthwhile.

The large and stable individual differences in recognition performance and the improvement in performance with practice suggest the possibility of using photographs like the ones made for this study for the selection and training of photointerpreters.

VISUAL IMAGE INTEGRATION AS
A FUNCTION OF CONTRAST, PROJECTION RATE, AND
NUMBER OF INDEPENDENT PHOTOGRAPHS

The improvement of photographic signal-to-noise ratio through photographic superimposition has long been recognized. This improvement is obtained by printing, in precise register, several negatives of the same scene. The image (signal) is coherent (uniquely constrained in area) from one scene to the next, but the noise (grain pattern) is not. Therefore, superimposition increases the strength of the signal more than the strength of the noise. This improvement in signal-to-noise ratio should improve the recognizability of the image.

Practical photographic superimposition systems can be quite complex and expensive. Consequently, the question arises as to whether or not the human visual system can be used to improve photographic signal-to-noise ratio. More specifically, the question is: can the recognizability of photographic images be improved by a rapid presentation of different photographs of the same image? The notion here is, with the aid of the visual system, that time may be sufficiently compressed to produce what might be called "perceptual" superimposition.

The purpose of this study was to explore various conditions under which image recognition might be enhanced by visual "superimposition" or "integration." More specifically, the purpose was to explore the effects of variations in contrast, in photographic projection rate, and in the number of independent photographs of a target upon the human observer's ability to recognize that target. A limiting condition of the study was that the target would be "grain limited"; that is, that it could not be recognized in any single photograph because of the relation between its size and the size of the grains in the photographic emulsion.

METHOD

Experimental Variables

The effects of three variables on the accuracy of recognition were explored:

Projection Rate: 2, 8, 16, and 24 frames per second¹

Contrast: 1.1:1, 1.71:1, and 3.83:1

Number of Independent Photographs: 2, 4, 8, and 16

Continuous loops of 16-mm motion picture films were used. The phrase "number of independent photographs" indicates the number of different grain patterns used in each loop. For example, for two independent photographs, every other photograph was identical: A-B-A-B..., but the grain patterns in photographs A and B were different random patterns. For four independent photographs, the identical photographs occurred in the sequence A-B-C-D-A-B-C-D...; the grain patterns in photographs A, B, C, and D were different random patterns. As will be described in more detail later, the film loops were prepared using an aerial image optical printer.

Contrast was the ratio of the average transmission of the targets (20 capital letters) to the average transmission of the grain pattern. The transmission measurements were made using a

STAT Densichron. Low contrast values were selected for study because it was felt that visual image integration would not be employed as a practical tool except for high spatial frequency, and thus low modulation, images.

Preparation of Photographs

The preparation of the photographs can best be described in

¹The projection rates were measured after the experiment: the actual values were found to be 1.98, 7.91, 18.2, and 23.6 frames per second.

two phases. In the preliminary phase, one of trial and error, the purpose was to determine the desired contrast ratios and the ratio of target-to-grain size required to achieve grain-limited target images. In the final phase, 12 continuous loops of 16-mm film were produced, each loop representing one of the 12 combinations of three contrast levels with four numbers of independent frames.

Preliminary Phase

The desired contrast ratios were obtained in the following steps:

1. A white card was photographed² over a range of exposures to produce a series of transparencies that varied in opacity from a clear film base to almost an opaque black.
2. A positive transparency of photographic grain (a grain sheet) was produced by enlarging a partially exposed negative.
3. Each transparency produced in Step 1 was optically superimposed over the grain sheet and photographed with an aerial image optical printer. The result was a series of grain photographs that varied in density.³
4. The darkest grain photograph was chosen to represent the density of the letter images in the final film loops. The densities of the remaining photographs were measured and compared with the standard. Three grain photographs were selected to achieve contrast ratios of approximately 4:1, 2:1, and 1.4:1.⁴ This procedure identified the exposure times required to achieve the desired contrast ratios for the final film loops.

² 35-mm Plus-X film was used throughout except for the final 16-mm loops.

³ It was decided at the outset that during this initial phase it would be easier to determine the appropriate contrast ratios by varying the background grain pattern density rather than the letter-target density.

⁴ Density measurements were made with the Densichron.

The required letter size was obtained in the following steps:

1. Four matrices of 20 letters were drawn in black on transparent celluloid. The size of the letters differed from one matrix to another but were the same within a matrix.
2. Each matrix was placed on a white background and photographed using an exposure time appropriate for the highest contrast ratio (4:1).
3. Each of the four resulting negatives of the letter matrix was superimposed on the original grain sheet and photographed with an aerial image optical printer. In each case, the letter images were defocused to achieve an amount of blur that appeared appropriate for the grain size. The result was four matrices of "grainy letter images," each with a contrast ratio of approximately 4:1.
4. Three subjects (Ss) viewed a positive transparency of each matrix of "grainy letters." The letter size that resulted in approximately 35% correct recognitions was selected as the size to be used for all contrast ratios.

Final Film Preparation

1. To simulate different grain patterns associated with independent photographs of the same image, a set of 2, 4, 8, and 16 different areas of the grain sheet were photographed. Each set of areas was photographed repeatedly to produce a 5-foot (200-frame) grain strip. To illustrate this last step, consider the case of four different areas of the grain sheet; call them A, B, C, and D. They were photographed A-B-C-D-A-B-C-D and so on until the 5-foot grain strip had been produced.
2. Twelve matrices of 20 letters each were drawn in black on transparent celluloid. There were four rows of 5 letters in each matrix and the location of the specific letters within each matrix was determined randomly. Three groups of four matrices were selected randomly from the twelve letter matrices.
3. Each group was photographed against a white background at each of the three predetermined exposures. The result was twelve negatives with letters of equal density (clear letters), but, of course, the background densities differed among the three groups of matrices.

4. Production of the grain-limited letter images was accomplished by superimposing the three groups of letter negatives over the grain strip with the aerial image optical printer. As noted before, the letter density was constant across the three groups of negatives, but the background density varied. Consequently, the superimposition of these negatives over the grain strip resulted in three levels of attenuation of the background grain and one level of letter grain; that is, three contrast ratios.

The letters were defocused to achieve blurring appropriate for the grain size. A 5-foot strip of 16-mm film was prepared by photographing the letters and a frame of the grain; that is, advancing the grain one frame, photographing the combination again, advancing the grain another frame, photographing again, and so on. The results of all this was twelve film loops that represented the three levels of contrast and the four levels of numbers of independent photographs.

Experimental Design

There was a total of 48 experimental conditions: four projection rates, three contrasts, and four numbers of independent photographs, $4 \times 3 \times 4 = 48$. The design is illustrated in Figure 1. Separate groups of 12 Ss served under each of the four projection rates. Each group observed each of the 12 film loops.

The presentation order of loops was randomized within each group (or projection rate). But with the restriction that each contrast appeared twice and each number of independent photographs appeared no more than twice in the first and last half of the experimental sessions.

Equipment

A L-W Photo, Photo-Optical Data Analyzer with a 2-inch focal length lens was used to project the images on a Polacoat, Type L560, 120 Plexiglas, back-projection screen. The projection equipment was installed in one of HFR's mobile laboratories, an 8' x 40'

CONTRAST		$C_1 = 1.1:1$				$C_2 = 1.71:1$				$C_4 = 3.83:1$				Ss
NUMBER OF INDEPENDENT PHOTOGRAPHS		F ₂	F ₄	F ₈	F ₁₆	F ₂	F ₄	F ₈	F ₁₆	F ₂	F ₄	F ₈	F ₁₆	
PROJECTION RATE (frames/sec)	2													1 - 12
	8													13 - 24
	16													25 - 36
	24													37 - 48
TOTAL NO. SUBJECTS														48

Figure 1. Experimental design.

trailer. The projector, projector stand, light box, and projection screen were securely fastened together to minimize differential vibration between the projector and the screen.

Projector flutter (that is, image registration from frame to frame) was measured after the experiment. It was found to be approximately 1/100 the size of the letters to be identified and was not different for the four projection rates used. On the basis of these measurements, projector flutter was judged not to be a significant factor in the results of the study.

Subjects

The Ss were students at Brooks Institute of Photography in Santa Barbara, California. They volunteered to participate in the experiment, and each was paid two dollars. The Ss expressed interest in the experiment and seemed to want to do a good job.

Procedure

Two to four Ss were run at a time. Before the experimental session began, they were seated in front of the projection screen and allowed to adapt to the ambient illumination for a period of ten minutes. They were then given answer booklets containing 12 pages like the one shown in Figure 2.

Name _____

R _____

C _____

F _____

Figure 2. Example page of answer booklet.

The following instructions were read:

You will be participating in an experiment to determine how well photographic images can be integrated over time by the eye under grain-limited conditions. By grain limited, I mean that the image is not recognized because of the relative sizes of the grain and the image. Essentially, the image appears to be fractured.

As you may know, studies have shown that the recognition of grain-limited images can be enhanced if independent frames of the same image are superimposed either optically or photographically. In a practical sense, this means that a grain-limited image in one frame of photography can be recognized if additional frames of the same object are obtained and superimposed. Although we know the limits of photographic and optical integration of grain-limited images, we do not know how well the eye can integrate these images over time, or the extent to which integration depends on the number of independent frames of the same image.

Your task will be to identify each of 20 letters of the alphabet which will be projected on the screen in front of you. The missing 6 letters will be G, M, Q, U, W, and Y. You may write these on the front cover of your answer booklet.

Now if you will look at the booklet we passed out to you, notice there are four rows and five columns or a total of 20 squares. When you have identified each letter, place your answer in the square corresponding to the position of the letter you see on the screen in front of you.

Because you will be looking at grain-limited letters under different conditions, you will discover that recognition may, in some instances, be very difficult, if not impossible. Even so, we want you to make the best guess you can. Don't leave any square blank unless you absolutely have to.

Are there any questions?

An example was given of the size of the letters the Ss could expect to see. The viewing distance was such that the letter target subtended a visual angle of approximately 28 minutes, which is well above the normal visual acuity threshold of one minute.

Before each film loop was projected, the experimenter gave the Ss two numbers to write in on the answer sheet; one number denoted the contrast (C) and the other the number denoted the number of independent frames (F) for that loop. Since each S observed all 12 film loops at only one projection rate, the space adjacent to the letter R on the answer sheet was only filled in on the first page of the answer booklet.

The Ss observed each loop being projected for four minutes. They rested for one minute after each loop was projected. Thus, each experimental session lasted approximately 70 minutes.

Control Condition

As previously stated, a limiting condition of the study was that the targets (in this case, the letters) to be identified were grain limited; that is, that they could not be recognized from a single photograph because of the relative target and grain sizes. Therefore, a control condition was run in which three Ss examined each frame of each film loop under still-projection conditions. The Ss examined each frame until they were satisfied that they could no longer identify any additional letters. The number correct for each S for each loop was the number of letters correctly recognized at least once. For example, if S recognized the letters A, B, C, on frame one and C, D on frame two of two frames, his score was 20% (4/20).

Table 1 shows the mean percentage of letters correctly recognized on each film loop under the still-projection conditions.

Table I

Mean Percentage of Letters Correctly Recognized
by the Control Group by Contrast and
Number of Independent Frames

Contrast	Number of Independent Frames			
	2	4	8	16
1.1:1	00.0	00.0	00.0	00.0
1.71:1	18.3	40.0	56.7	65.0
3.83:1	55.0	70.0	71.7	83.3

RESULTS

The mean percentage of correct letter recognitions for all 48 experimental conditions is shown in Table II.

It is evident from the table that at the lowest contrast (1.1:1) visual integration provided very little, if any, additional information. For that reason, no additional analyses were made of the data from the 16 low contrast, experimental conditions, and subsequent tables, figures, and discussions will be concerned only with the two higher contrasts.

One of the mean values in Table II appeared to be inconsistent, the value of 36.7% for a projection rate of two frames per second, a contrast of 1.71:1, and 16 independent photographs. Examination showed that that experimental condition had been administered first to all 12 Ss. If performance on the task was improving with the practice implicit in observing one film loop after another, then performance on a given film loop (a particular experimental condition) would depend, in part, on the ordinal position in which it was observed.

To ascertain whether learning was taking place and to estimate

Table II

Mean Percentage of Correct Letter Recognitions
for All Experimental Conditions

CONTRAST		$C_1 = 1.1:1$				$C_2 = 1.71:1$				$C_3 = 3.83:1$			
NUMBER OF INDEPENDENT PHOTOGRAPHS		F ₂	F ₄	F ₈	F ₁₆	F ₂	F ₄	F ₈	F ₁₆	F ₂	F ₄	F ₈	F ₁₆
PROJECTION RATE (Frames/sec)	2	2.9	0.0	1.7	0.4	44.2	47.1	48.7	36.7*	64.6	67.5	72.1	78.3
	8	0.4	1.3	0.0	1.3	45.4	44.1*	53.3*	73.3	67.1	79.6	90.0	93.3
	16	0.8	2.1	0.8	0.8	23.8*	43.8	55.4	53.3*	62.1	74.2	83.3	83.8
	24	0.8	0.8	0.8	0.0	21.2*	37.5	45.8	65.0	65.0	75.0	83.3	87.1

* Conditions rerun

the reliability of performance for selected experimental conditions, a group of eight of the original 48 Ss was run a second time on six of the 16 medium contrast (1.71:1) experimental conditions. (The group of eight Ss will hereafter be referred to as Group II, and the original 48 Ss will be referred to as Group I.) The six conditions designated with asterisks in Table III were selected for replication because performance on them seemed to be inconsistent with that on the remaining conditions.

Group II correctly recognized 63.6% of the letters on the original set of four C₂ experimental conditions and 77.2% on the six rerun conditions. The difference between these means was statistically significant ($t = 3.27$, $P < .025$). This result indicates that learning did occur during the course of the experiment.

Further evidence for this conclusion was obtained by comparing the performance of Group I on the six experimental conditions observed first and the six observed last. The mean percentage of correct recognitions was 58.0 on the first six conditions, and 65.7 on the last six.

Because of this learning effect the differences in the magnitudes of the percentages shown in Table II are, in part, a result of the differences in the ordinal position in which the experimental conditions were observed.

Although Group II was run to check on the reliability of the results for selected experimental conditions, this check could not be considered valid because it was later discovered that Group II was not a representative sub-sample of Group I. A comparison of the mean performances of the eight Ss in Group II with mean performances of the remaining 40 Ss showed that Group II was superior at the task. The mean percentage of correct recognition was 63.6 for Group II and 42.4 for the remaining 40 Ss. Consequently, the data obtained from rerunning Group II were not included in the subsequent analyses.

There is little doubt that the Ss' performance was improving during the experiment. Because of this improvement, and because the presentation order of the 12 experimental conditions (three contrasts x four numbers of independent photographs) was confounded with projection rate, it was not possible to evaluate unambiguously the effects of any one of the 12 experimental conditions for any one projection rate.

Despite the aforementioned difficulty, the effects of projection rate, contrast, and number of independent photographs could be evaluated at least for the stage of learning represented in the study. If projection rate is disregarded as a variable, the latter two variables were counterbalanced adequately in the design. Put in another way, only the main effects of the three variables could be evaluated; the interaction of projection rate with contrast or with number of independent photographs is contaminated with the effects of presentation order (learning).

Table III shows the analysis of variance of the number of letters correctly recognized by Group I.

Table III

Analysis of Variance of the Number of
Letters Correctly Recognized

<u>Source of Variation</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Between Ss	<u>47</u>	<u>106.4</u>	
Projection Rate (A)	3	89.0	0.83
Error	44	107.6	
Within Ss	<u>336</u>	<u>21.6</u>	
Photographs (B)	3	346.3	50.93*
Contrast (C)	1	3,638.0	535.00*
A x B	9	43.7	6.43*
A x C	3	18.3	2.69
B x C	3	0.7	0.10
Error	317	6.8	

* $P < .001$

The table shows that there were no reliable differences in recognition accuracy among projection rates. The mean percentages of correct recognitions for projection rates 2, 8, 16, and 24 frames per second were 58.0%, 68.3%, 59.9%, and 59.4% respectively.

The projection-rate-by-number-of-independent-photographs interaction was statistically significant. But, as was pointed out earlier, the interactions with projection rate were confounded with learning. Consequently an unambiguous interpretation of this interaction was not possible.

The reliable difference in recognition accuracy between C_2 (45.9%) and C_4 (76.6%) was not surprising in that it is well known that increasing the contrast increases recognition accuracy.

Table III also shows that there were reliable differences in recognition accuracy among the different numbers of independent photographs. However, these differences should not be interpreted as evidence supporting the occurrence of "visual integration." The grain pattern was random from one photograph to the next, so it is reasonable to assume that the particular letters that can be recognized will not be identical from one photograph to the next. Therefore, increasing the number of independent photographs should increase recognition accuracy without any integration.

To demonstrate that rapid successive projection enhanced recognition, the performance of the Experimental Group must be shown to be superior to that of the Control Group. (As it was pointed out earlier, the Control Group viewed the photographs one at a time.) Figure 3 shows the percentage of correct recognitions by contrast and number of independent photographs for the Experimental and the Control Groups. Inspection of Figure 3 shows that recognition accuracy was positively related to the number of independent photographs for the Control Group as well as the Experimental Group. Also, there were no reliable differences in recognition accuracy between the Control and Experimental Groups for either contrast value. Therefore, there was no evidence supporting

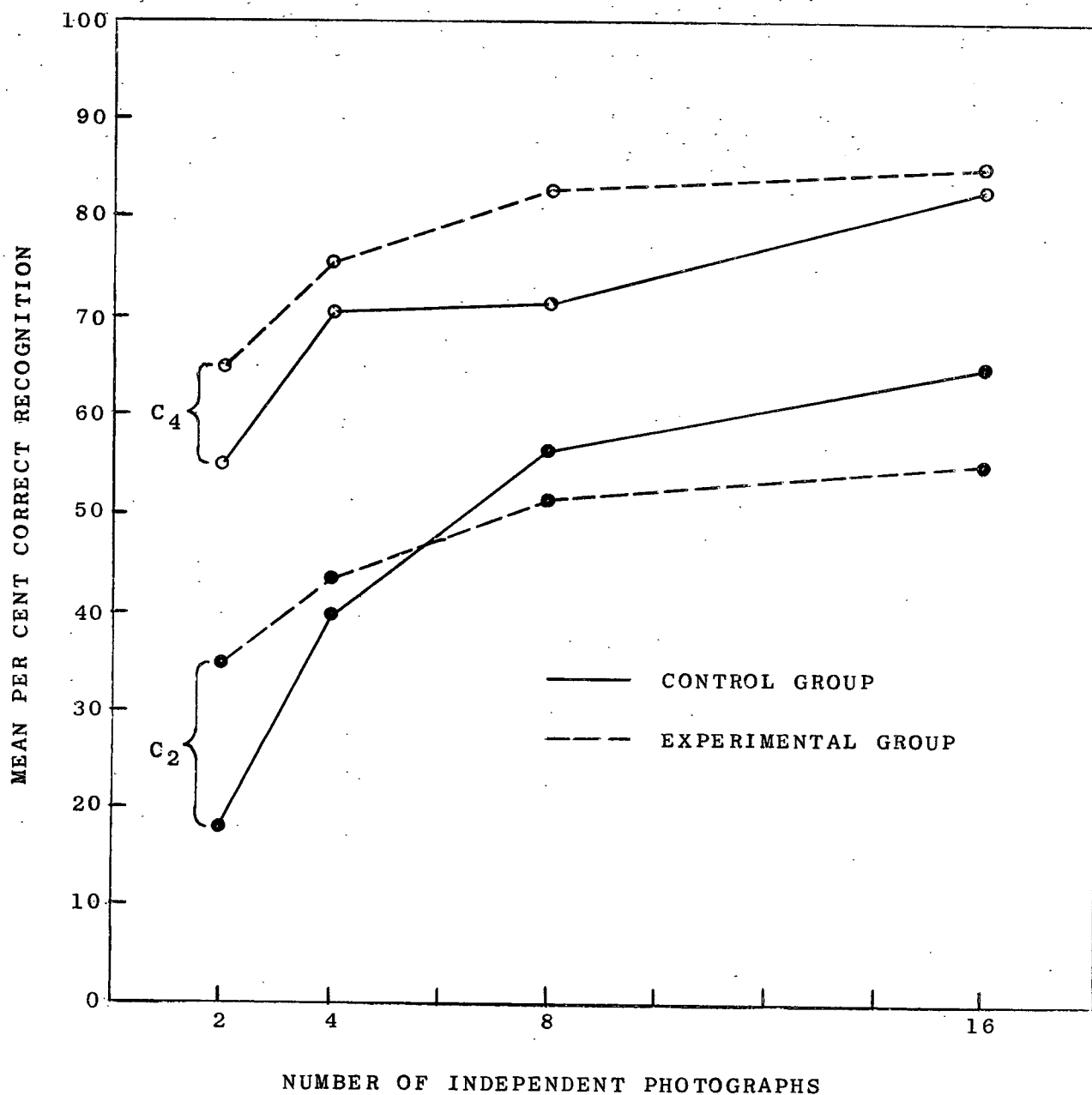


Figure 3. Mean percentage of letters correctly recognized as a function of contrast and number of independent photographs for the Control and the Experimental Groups.

the occurrence of "visual integration."

Individual Differences

The differences among individual performances were very large, particularly under the more difficult experimental conditions. Under several conditions, the scores for the 12 Ss ranged from zero to 100% correct. Furthermore, in spite of the learning that took place during the experiment, the differences remained reliable. As an example, consider the data for the first group of Ss under a projection rate of two frames per second and a contrast of 1.71:1. The first film loop the Ss observed contained 16 independent frames. The scores ranged from zero to 100% correct. The eleventh loop they observed contained eight independent frames, and again the scores ranged from zero to 100% correct. Even after the learning that apparently occurred during the observation of the first ten film loops, the rank-order correlation between individual recognition performances on the first (C₂ F₁₆) and the eleventh (C₂ F₈) loops observed was 0.82. The mean reliability of individual differences for all experimental conditions was 0.94. (This reliability was estimated from the analysis of variance in Table III.)

CONCLUSIONS AND RECOMMENDATIONS

The results of this study did not provide evidence for "visual integration." This was probably because of the use of projection rates which were too low. Observation of the stimulus materials showed that for all projection rates there was apparent movement of the grain spots within the letter boundaries and in the background. In other words, the letters did not appear to be solid, but instead appeared as many rapidly moving dark spots against a background noise of moving lighter spots. It may be that "visual integration" occurs only if the projection rate is high enough so that the grain spots on successive frames appear to occur simultaneously.

When two stimuli are presented successively and in different positions one will see what corresponds to reality: two stationary stimuli in succession. With a reduction in the time interval between presentations of the stimuli, there appears to be motion of a single stimulus from one position to another (known as the "phi phenomenon"). With a further reduction in the time interval, both stimuli appear to occur simultaneously.

The point at which the change from motion to simultaneity takes place is a function of many variables. Two important physical variables are the time interval between the presentation of the stimuli and the space between the positions of the stimuli. The shorter the space between the positions the shorter must be the time interval between presentations to achieve simultaneity. For example, when two vertical lines 1 cm apart are viewed at reading distance (about one degree of visual angle) and presented successively, the two lines appear to occur simultaneously if the interval is 30 ms or less. By reducing the separation between lines a shorter duration than 30 ms would be required to achieve the appearance of simultaneous occurrence.

In the present study the visual angle subtended by the letters was less than 0.5 degrees. Since the grain spots were randomly located within the boundaries of the letter in each frame, the separation between most of the grain spots on successive frames was, on the average, far less than 0.5 degrees. To achieve simultaneity of the spots with such small separations, the time interval between frames should be far less than 30 ms, and possibly as short as a few ms. Of course, the exact value of the interval necessary to achieve simultaneity would vary from spot to spot because the separation among spots varies. In any event the time interval between frames required to achieve simultaneity of the grain spots in the photographs is probably far less than 20 ms-- 20 ms being the interval between frames presented at a rate of 24 frames per second.

Assuming perceived simultaneity is a necessary condition for the occurrence of "visual integration," it is conceivable that frame rates of 100 per second or higher will be required. The rate required, if indeed there is such a rate, can only be established empirically since no information is presently available to make an adequate prediction about the complex stimuli used in the present study.

It is suggested, therefore, that an informal investigation be conducted with the photographs made for the present study using higher projection rates. A full-scale study of the limits within which the rapid presentation of independent photographs of grain-limited images enhances image recognition should be considered only if the results of the informal investigation show that it is worthwhile.

The results of the present study indicate that the accuracy of recognizing grain-limited images increases with successive exposures to the task. Consequently, if a full-scale study is conducted, it would be necessary to give the subjects sufficient experience with the task to stabilize performance prior to administering the experimental conditions.

A finding of further interest was the large and stable individual differences in recognition performance with the grain-limited images. The magnitude and reliability of the differences suggest the possibility of using photographs like the ones made for this study for photointerpreter training and selection.

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Approved For Release 2004/11/30 : CIA-RDP78B04770A000900060002-6

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